Low Cost Control System Components for High “G” Gun Launched Projectiles

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GENERAL DYNAMICS
Ordnance and Tactical Systems

What Makes a Low Cost Control System for a Gun Launched Projectile Unique?

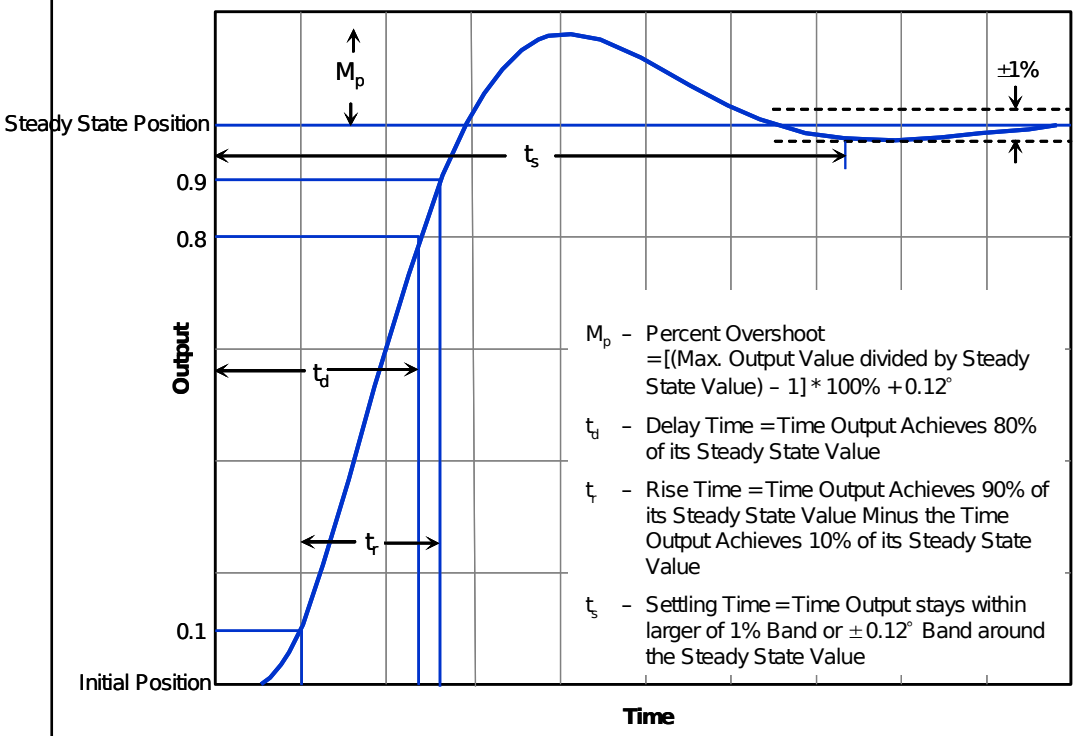
- **18,000 G's Launch Acceleration**
  - **Followed by 10,000 G Set-forward**
- **Precision Mechanical Components Compactly Integrated**
  - **Electronics Designed to Fit in Whatever Room is Left Over**
- **Cost as "Important" as Performance**
- **Electro-Mechanical System Functions AFTER Set-Forward / Set-Back Accelerations**

Typical Gun Launched CAS CONOPS

Typical Gun Hardened CAS Requirements

Criteria	Range of Requirement
Speed at deployment	Apogee to Mach 3
Altitude at deployment	Sea level to 80,000 ft
Roll rate at deployment	0 to 50 Hz
Fin loading at deploy	Zero to very large drag and panel loads
External pressurization at gun launch	Up to 4,000 psi
Deployed fin position	+/-20.0 deg
Fin-to-fin deploy time variation	< 10 msec
Deploy time	< 50 msec
Environmental conditions	20 yr storage life

Typical Step Response Specifications


M_p
±1%
Steady State Position
t_s
0.9
0.8
Output
t_d
t_r
0.1
Initial Position
Time
M_p – Percent Overshoot =[(Max. Output Value divided by Steady State Value) – 1]*100% +0.12°
t_d – Delay Time =Time Output Achieves 80% of its Steady State Value
t_r – Rise Time =Time Output Achieves 90% of its Steady State Value Minus the Time Output Achieves 10% of its Steady State Value
t_s – Settling Time =Time Output stays within larger of 1% Band or ±0.12° Band around the Steady State Value

Small Signal Step Response Specifications, No Load Condition

Specification	Value
Rise Time, t_r	12.0 msec
Delay Time, t_d	15.0 msec
Settling Time, t_s	39.0 msec
Max. Overshoot, M_p	10%

Small Signal Step Response Specifications, Loaded Condition

Specification	Value
Rise Time, t_r	15.0 msec
Delay Time, t_d	20.0 msec
Settling Time, t_s	39.0 msec
Maximum	10%

Large Signal Step Response Specifications, No Load Conditions

Specification	Value
Rise Time, t_r	45.0 msec
Delay Time, t_d	50.0 msec
Settling Time, t_s	115 msec
Max. Overshoot, M_p	10%

Large Signal Step Response Specifications, Loaded Condition

Specification	Value
Rise Time, t_r	75.0 msec
Delay Time, t_d	80.0 msec
Settling Time, t_s	190 msec
Maximum	10%

Small Step –Unloaded Step Response

Spec	Req	Mean (from test)	Deviatio (from test)	Sigma margin
Unloaded 1 deg 10-90%	< 12 ms	4.21 ms	0.349 ms	22.3
Unloaded 1 deg 0-80%	< 15 ms	7.32 ms	0.237 ms	32.4
Unloaded 1 deg Settling time	< 39 ms	7.83 ms	0.306 ms	102
Unloaded 1 deg Overshoot	< 22 %	6.92 %	2.94 %	5.13

Small Step –Loaded Step Response

Spec	Req	Mean (from test)	Deviation (from test)	Sigma margin
Opp load 1 deg 10-90%	< 15 ms	6.17 ms	0.957 ms	9.22
Opp load 1 deg 0-80%	< 20 ms	8.05 ms	0.390 ms	30.6
Opp load 1 deg Settling time	< 39 ms	8.98 ms	0.64 ms	46.9
Opp load 1 deg Overshoot	< 22 %	0.41 %	0.43 %	50.0

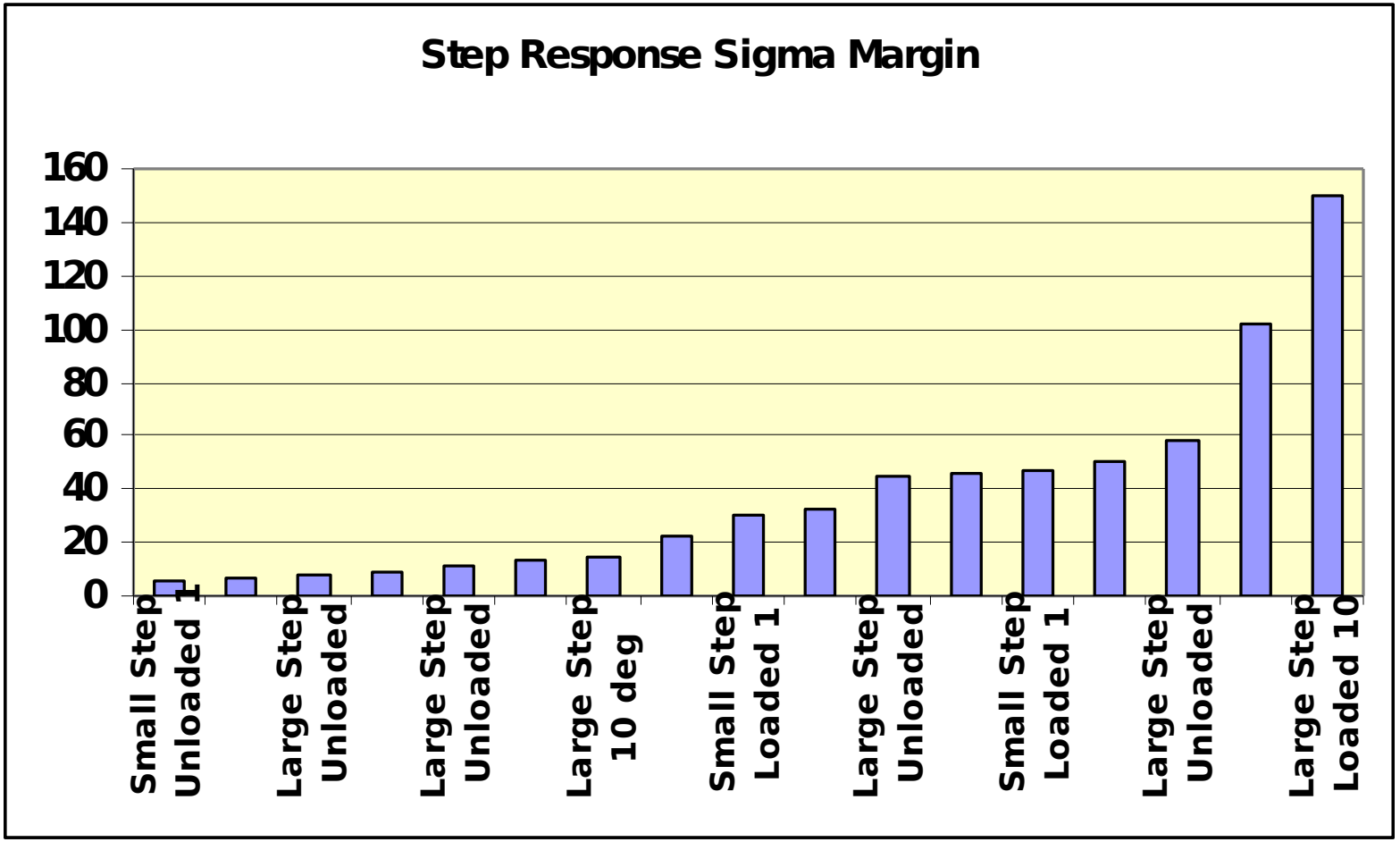
Large Step – No Loaded Step Response

Spec	Req	Mean (from test)	Deviation (from test)	Sigma margin
Unloaded 10 deg 10-90%	< 45 ms	30.2 ms	0.256 ms	57.8
Unloaded 10 deg 0-80%	< 50 ms	34.2 ms	0.354 ms	44.6
Unloaded 10 deg slew	> 214 deg/s	261.2 deg/s	3.38 deg/s	14
Unloaded 10 deg Settling time	< 115 ms	83.4 ms	4.1 ms	7.7
Unloaded 10 deg Overshoot	< 11.2 %	4.96 %	0.548 %	11.4

Large Step – Loaded Step Response

Spec	Req	Mean (from test)	Deviation (from test)	Sigma margin
Opp load 10 deg 10-90%	< 75 ms	30.1 ms	0.300 ms	150
Opp load 10 deg 0-80%	< 80 ms	34.5 ms	0.345 ms	45.5
Opp load 10 deg Settling time	< 190 ms	109 ms	12.4 ms	6.5
Opp load 10 deg Overshoot	< 11.2 %	3.64 %	0.542 %	13.9

High Statistical Margin is KEY to Low Cost Production



Control System Performance Spectrum

All Systems Have Survived Gun Launch Environments

ANSR

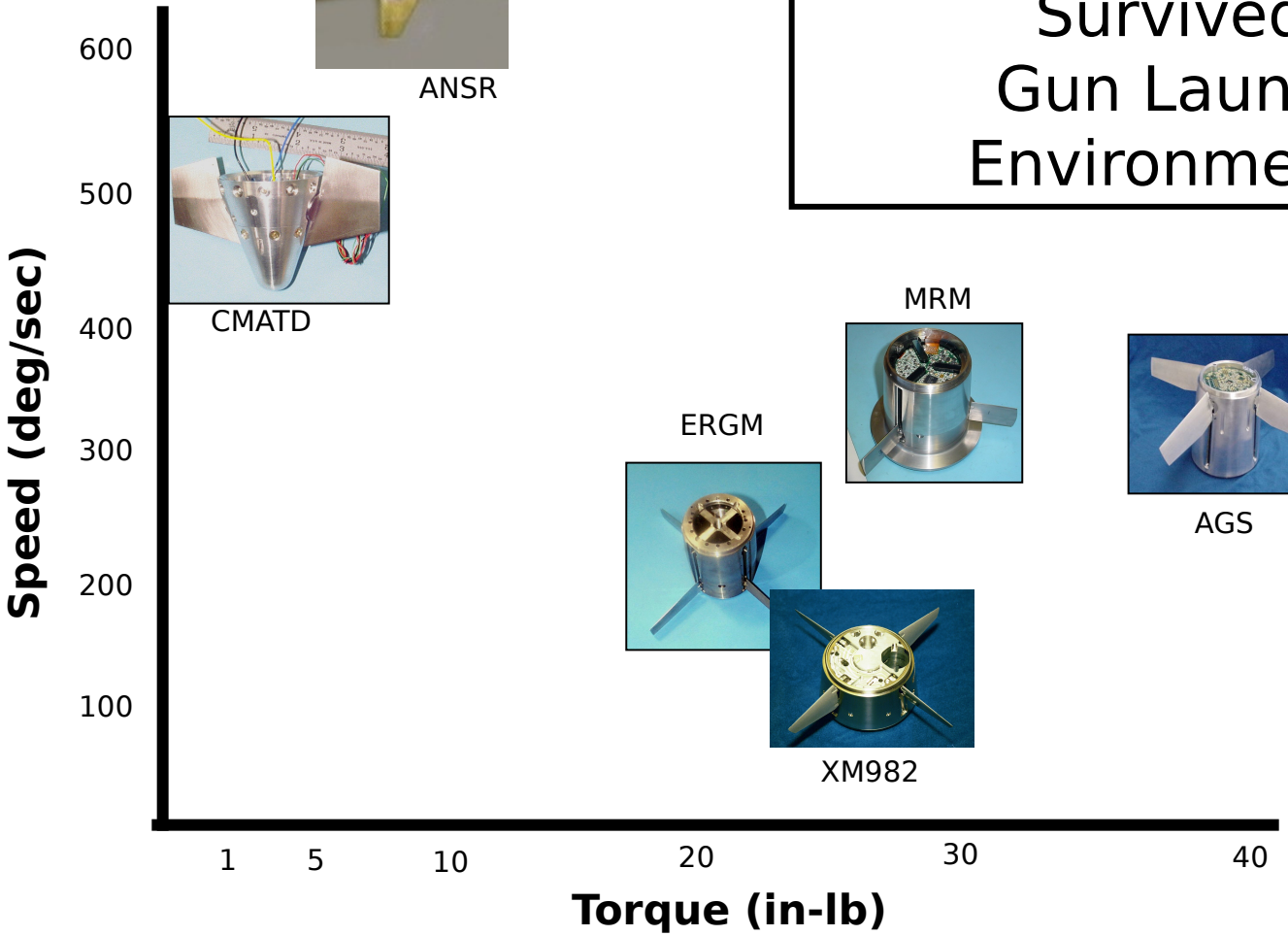
CMATD

MRM

ERGM

XM982

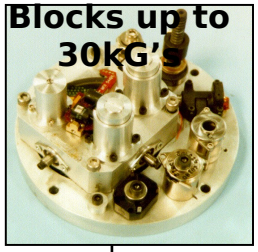
AGS



HISTORY of LOW COST / Hi- G MUNITION SYSTEMS

Stinger

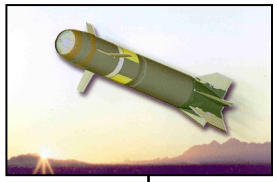
Gun Launched Component Qual Building Blocks up to 30kG's



CMATD 16,000 G's

XM982 18,000 G's

ANSR 9,600 G's



MRM 10,000 G's

BAT ATACMS

ERGM 12,500 G's

AGS 18,000 G's

1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 200

GENERAL DYNAMICS
Ordnance and Tactical Systems

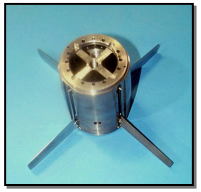
Considerations for G-Hardened Survivability – … At a Low Cost

- **Motor Fabrication and Assembly**
  - **All Processes Controls In-house**
    - Auto-winding with precision wire termination, staking, and encapsulation
- **Feedback Device Assembly**
  - **No “black box” subassemblies**
- **Commercial ICs**
  - **Control of PEMS through In-House Qual plan**
  - **Vendor Change Notification Contracts**
  - **Rigorous Qualification Test Program**
- **Thorough Manufacturing and Assembly Discipline**
  - **Detailed Process Control**
    - Visual work instructions
    - Stringent adherence to KPI
  - **6-Sigma Design and Manufacturing Philosophy**

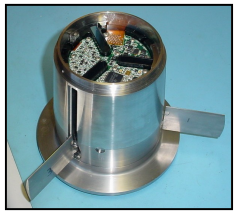
MULTI-PROGRAM COMMONALITY

AGS

ERGM

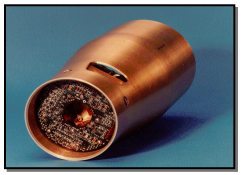


MRM

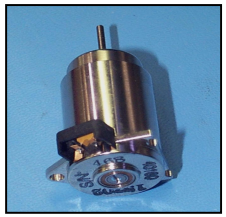


XM982

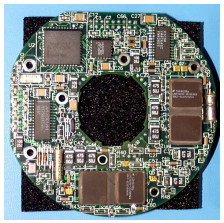
BAT



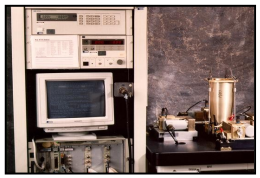
Key to Low Cost Munition Controls



- Motor
- Potentiometer

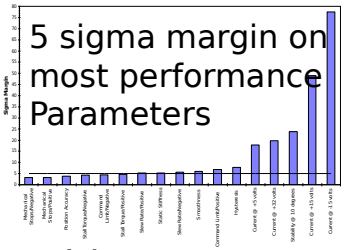


- Schematics
- PEMS

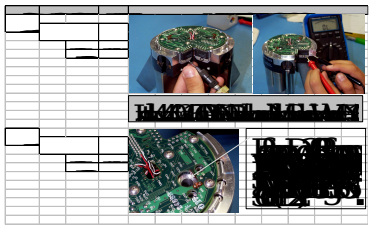


- TE Design
- Tooling

Common Production



Multi Program SPC



Standardized Work Instructions

Low Cost

ELEMENT	% of BOM
Motor	36
Reducer	8
Electronics	
Loop	8
Power	4
Potentiometer	4
Assembly	10
Recurring Test	6
Total	70%

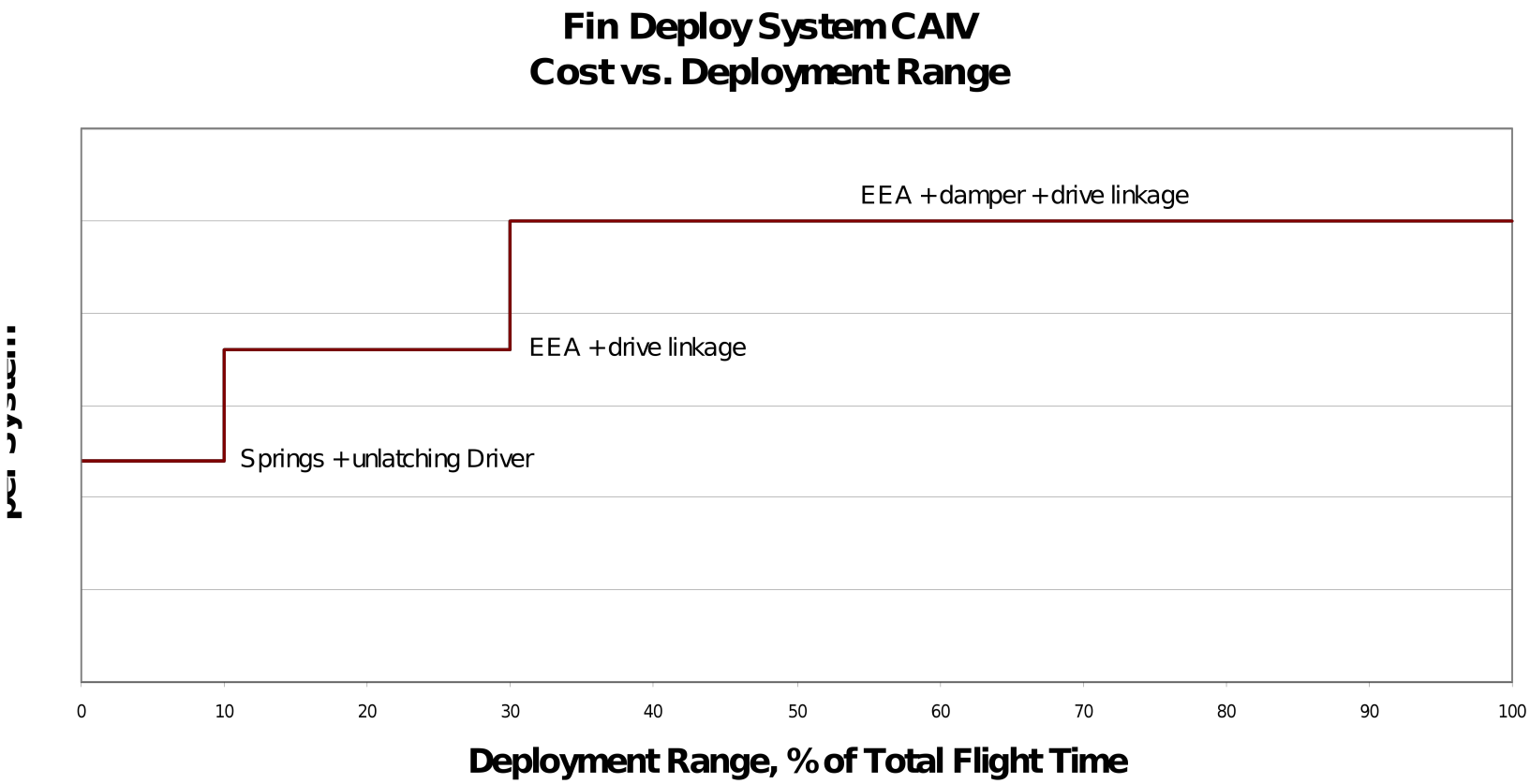
Commonality from Program to Program

Control System Configuration Considerations

- **1, 2, and 4 axis Control Actuation Systems**
  - **Aero-Performance and Gun Configuration are Typical Drivers**
  - **Compact Packaging Always a Challenge**
    - Multiple ICDs impose confusion and cost
- **Cover Release and Fin Ejection Systems**
  - **Deployment Conditions**
    - Aft vs. forward deploy
    - Variation in altitude, speed and AOA
    - Fin-to-fin deploy time variation
  - **Deploy System Drivers**
    - Pyrotechnic (EEA)
    - Electro-magnetic Motor
    - Stored Energy
  - **Deploy Fin Lock Requirements**
    - Stop impact energy
  - **Fin Slot Sealing**
    - Mechanical device vs. Electro-Explosive Actuator

Cost Drivers - Fin and Cover Systems

- **CAIV Trades**

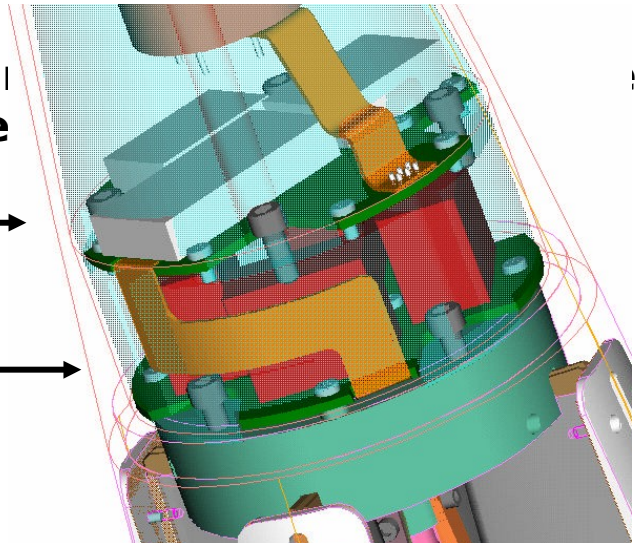


Auxiliary Functions

- **Power Conditioning**
- **Second Arming**

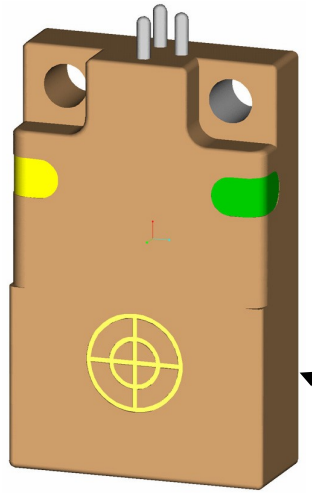
Power Conditioning

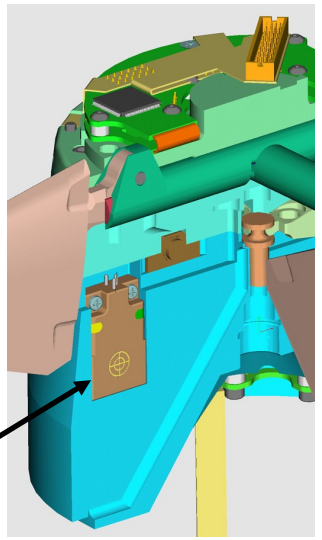
- **CAS Typically Represents the Primary Power "User"**
  - **Integral packaging eliminates routing of high power between sections**
- **Integration of PCU Elements within the CAS Has Advantages**
  - **Isolation of Noise**
  - **Optimal Use of Otherwise Unusable Volume in the CAS Section**
- **Current PCU Designs Address Several Areas**
  - **Voltage Limiter – Control maximum voltage to protect sensitive components**
  - **Voltage Regulation – Precision [illegible] levels from multiple battery source le[illegible]**
  - **Gun hardening tests to 15Kg**



Second Arming

The Challenges	Solutions
• Reliable Determination of Launch of Fin Deploy	Positive Detection Beyond Gun tube ID
• Sensor Gun Hardening 30Kg	Sensor Centrifuge Tested to





Sensor Mounted in CAS

CONCLUSION
Low Cost / High "G" Gun Launched Projectiles

- **Missile Must Maneuver AFTER Launch from Gun or Cannon**
  - **9,000 to 18,000 G's are typical**
    - Next Generation Projectiles are Exceeding 30,000 G's
- **Control Actuator System Must Survive High G-Forces**
  - **Electro-mechanical includes:**
    - Motors
    - Reduction Mechanism
    - Control Electronics
      - Includes Software
    - Fin/Canard/Cover Restraint/Deploy Mechanism
  - **Often Includes Auxiliary Functions**
- **Control Actuator System Must Survive Economic Forces**
  - **All Performance Specifications, Environmental Requirements Must be Met**
  - **Lower CAS Cost Challenges are Constantly Being Introduced**
    - Non-Traditional CAS Design and Production Objectives Must be Considered